# Image characterisation based on the mammalian visual cortex

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## ABSTRACT

A proposal for a model of the primary visual cortex is reported. It is structured with the basis of a simple unit cell able to perform fourteen pairs of different boolean functions corresponding to the two possible inputs. As a first step, an model of the retina is presented. Different types of responses, according to the different possibilities of interconnecting the building blocks, have being obtained. These responses constitute the basis for an initial configuration of the mammalian primary visual cortex. Some qualitative functions, as symmetry or size of an optical input, have being obtained. A proposal to extend this model to some higher functions, concludes the paper.

**Keywords:** mammalian visual cortex, retina, image processing, image characterization.

## 1. INTRODUCTION

One of the more active topics in the last decades has been trying to discover how interactions between neurons in a brain lead to meaningful patterns of neural activity and ultimately to perception, behaviour, and even intelligence. The main problem concerns the possibility to break down the complexity of the vertebrate brain so that we can gain some understanding of higher integrative brain function. Two obvious ways are to work on either simpler nervous systems or on simpler parts of more complex brains. Both approaches have been and are being successfully taken. The first one deals with invertebrates whose brains contains many fewer neurons. The second one is to study well-defined and perhaps simpler parts of the vertebrate brain. The cerebellum, the olfactory bulb, and the visual system are brain regions that have been the subject of substantial research. The visual system has been particularly attractive, because it is easily stimulated with light and because it is naturally divided between eye and brain.

According to above facts, the mammalian visual cortex constitutes a main topic for biologists, physiologists and neurologists. The reason of this interest is due to several factors. The first one is related to the importance of the vision processes in the relationship between the living beings and their environment. On the other hand, is the large number of functions carried out by the visual cortex. Besides the above facts, the visual cortex possesses other characteristics that justifies its study. These reasons are those derived from the previously mentioned great amount of information that is processed and the way is done. The form of processing images in parallel is superior to the way in which it is done by most of the present artificial vision systems. To try to obtain some lessons from the way the visual cortex works can be a very good exercise. These lessons could be adopted and implemented in other systems.

One of the most interesting topics to be studied is the way information is processed. Visual processing in human beings involves the analytical abstraction and separation of submodalities as well as the integration of the abstract representation of those submodalities into a unified percept. The unified percept, however, is not confined to one location; it is distributed across the different processing areas, bound together by the multiple anatomical connections between them. We are presently in a phase when the evidence for multiple areas specialized for processing different submodalities dominates this working area. The abstracted visual image is distributed between many different areas. There must therefore be mechanisms for combining the different operations in order to reconstruct some kind of coherent representation of the visual image. This is sometime referred as "the binding problem". Since this must take place over some period of time while we perceive an object, there must be continuing interactions between the different areas, presumably mediated by the rich reciprocal connection between them. This process of reciprocal reexcitation is referred as "reentry". One possibility is that these reciprocal interactions occur in rhythmic fashion; oscillatory waves at specific frequencies may be involved[1].

Many works have been carried out along this way in the last years. Detailed journal articles describing a variety of neurovision system architectures for preattentive vision, visual perception, object recognition, colour vision, stereo vision, and image restoration are included in [2]. A very interesting selection of technical papers, concerning Neurocomputing, is the two volumes set [3-4]; it contains a wide range of approach to this topic with many of the seminal works.

In the present work we will try to present another possible approach to the same problem. The basis will be some previous works[5-8] concerning a part of the mammalian retina. A part of this work will be presented here as well as some new approaches

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to the same problem. Following the same line, the second part of the paper will propose a model of the visual cortex. Some high level functions, as symmetry detection and number of borders, will be obtained. A more complex model of the visual cortex, trying to obtain a certain degree of complexity in the extraction of knowledge, will be the final part of the present work. A similar unit cell will be employed in any of these cases.

## 2. NEUROPHYSIOLOGICAL BASIS OF THE MODEL

One the first and more important papers dealing, from a general point of view, with the general aspects of the biological vision system was the work of D. Hubel and T. Wisel[9]. They postulate a functional architecture that may underline the processing of sensory information in the cortex. This work, and a large number of others that follow this one, have set the roots for a better understanding of many visual detection aspects in mammalians. The main lines of our present knowledge are now very well settled.

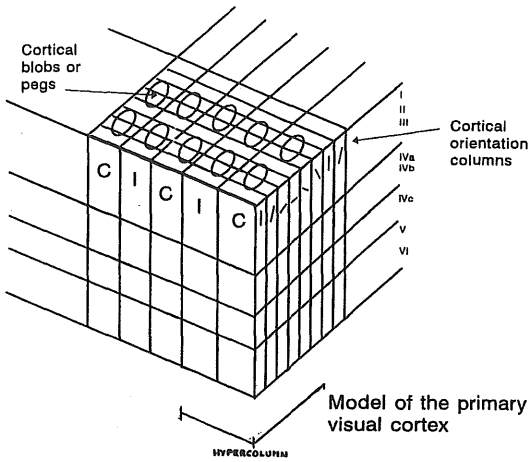


**Figure 1.-** Structure of the primary mammalian visual cortex.

Groups of neurons in the visual cortex process information about form, contrast, on, movement, and colour of objects in the external world. In the primary area, known as $V_1$, area 17, or striate cortex, neurons ignore uniform illumination. Those involved in the initial stages of pattern recognition require highly specific shapes or forms – in particular lines or edges with a certain orientation or position on the retina. Some categories of neurones are specialized to respond to angles or corners or to movements in one direction but not in other (Fig. 1). According to the type of information they carry, cortical neurons have been classified as simple and complex. Individual cortical neurons receive inputs from corresponding areas of retina in both eyes, with similar receptive field organization. Neighbouring simple and complex cells share common functional properties; such cells are stacked in the form of columns that turn at right angles to the cortical surface. Within these columns, cells that deal with colour are grouped in separate clusters known as blobs. Most blob cell' receptive fields are circular. Aggregation of cortical neurons with related receptive field positions and functional makes it easier for them to interconnect so that they can perform the type of analysis required of them. Maps in visual areas of the cortex are not simple representations of the retina.

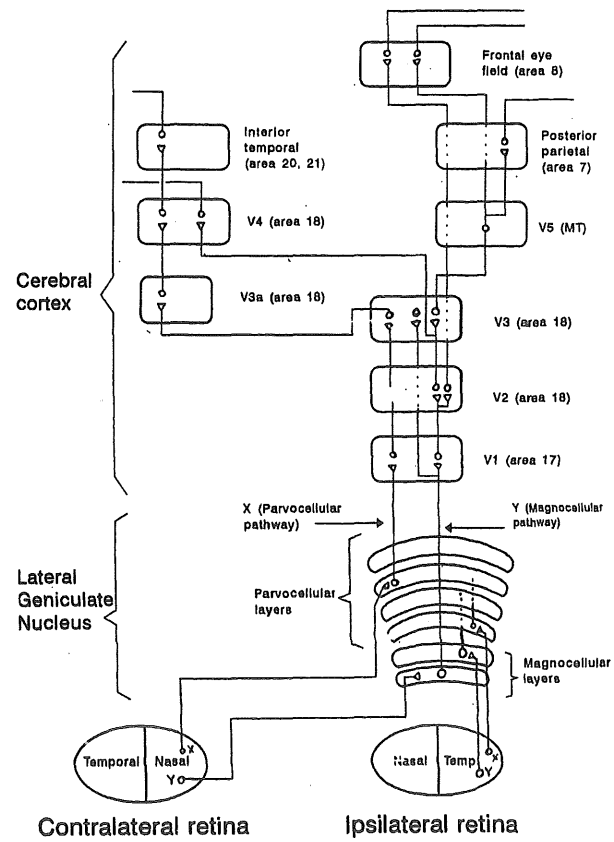


**Figure 2.-** General scheme of the different pathways at the visual cortex.

Several lines of evidence indicate that specialized lines of transmission project from relay to relay through the primary visual cortex and then on to the higher visual areas known as $V_2$, $V_3$, $V_4$, and $V_5$. These pathways, each of which is primarily concerned with information about either depth, movement, colour, or form, are supplied by inputs originating from one of the two division of the lateral geniculate nucleus. The two main pathways, parvocellular and magnocellular, have different characteristics concerning the type of information they transmit (Fig. 2). Parvocellular is concerned with form and colour, and have small receptive field. Neurons in the magnocellular pathway have larger receptive fields and detect small changes in contrast. Higher regions of the cortex such as $V_4$ and $V_5$ contain cells responding mainly to colour or to movement.

## 3. STRUCTURE OF THE FUNDAMENTAL BUILDING BLOCK

As it has been pointed out before, a simple cell has been the basis for the architecture of the proposed system. This cell has been employed by us as the main block for some structures in optical computing[10-13]. Its characteristics have been presented in several places and they may be synthesised as follows. The basic structure is shown in Fig. 3. It is composed by two non-linear elements: an on-off device and a SEED-like device. Their characteristics are shown at the inset of Fig. 3. It has two signals input, $I_1$ and $I_2$ as well as and two control signals, h and g. The output is a set of fourteen pairs of signals, boolean functions of the inputs. When some feedback is added, for instance connecting a part of the output from $O_1$ as control signal to the P device, as well as a multilevel periodic input, some non-linear behaviour is obtained. Under certain conditions, and with a certain type of it is possible to obtain even a chaotic signal. Moreover, with no input, a periodic situation appears being the period a function of the feedback delay time.

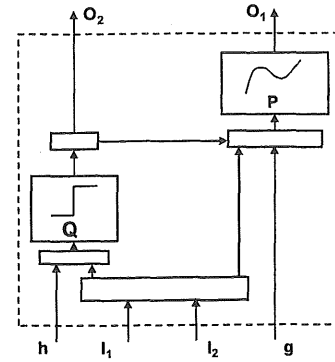


**Figure 3.**- Basic structure of the elemental block for the retina and visual cortex architectures.

## 4. BASIC BEHAVIOUR OF THE RETINA

Because the retina is the first place from where the external sensations go into the living beings, it deserves to be the first place for an initial processing of the signal.

The retina is quite different from any of other mammalian sense organs in that a good deal of the neural processing of the afferent information has already occurred before it reaches the fibres of the optic nerve. The fibers of the optic nerve are in fact two synapses removed from the retinal receptors, and particularly as far as the rods and cones in the periphery are concerned, there is considerable convergence of information from large groups of receptors. What happens is that receptors synapse with bipolar cells, and these in turn synapse with the million or so ganglion cells whose axons form the optic nerve. These two types of neurones form consecutive layers on top of the receptor layer and are mingled with two other types of

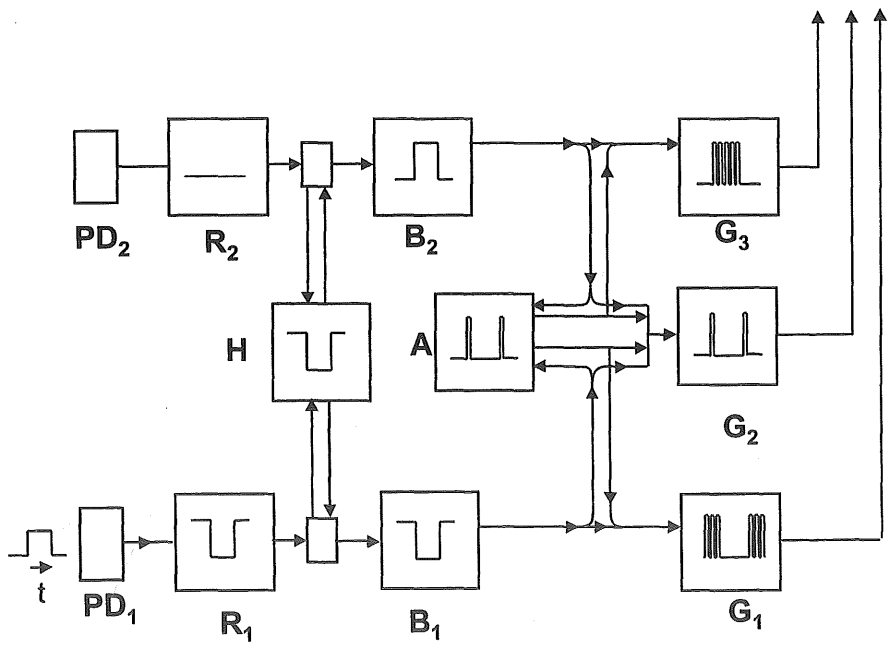


**Figure 4.**- Basic configuration employed as primary structure of the mammalian retina.

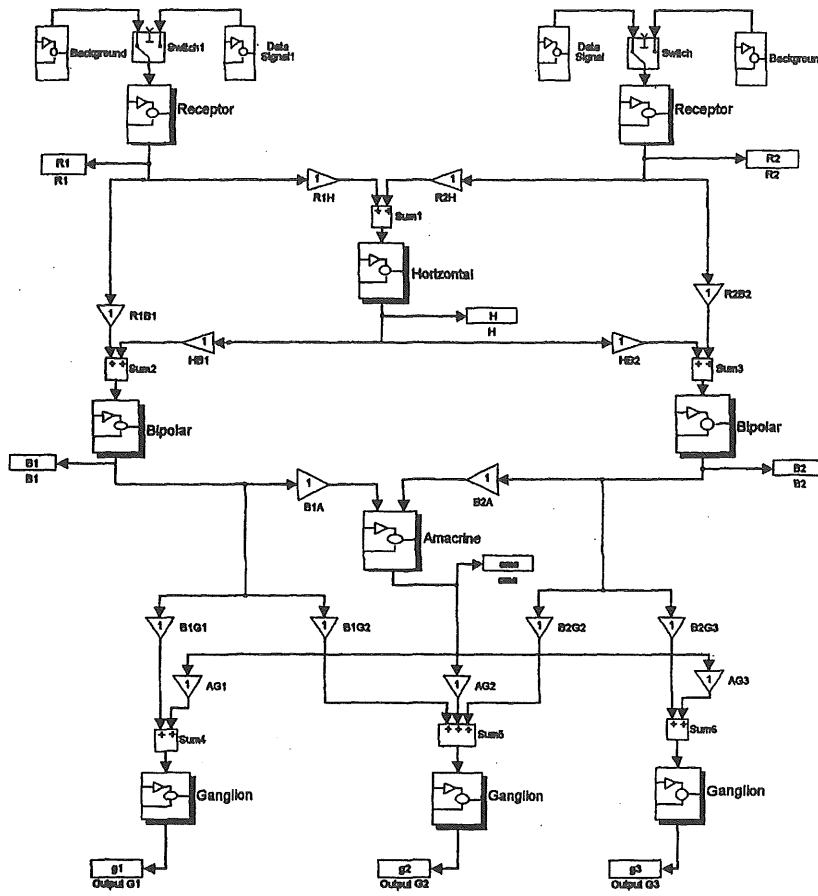


**Figure 5.-** Working scheme of the computer simulation of the retina.

interneuron that make predominantly sideways connections. These are the horizontal cells at the bipolar/receptor level, and the amacrine cells at the ganglion cell/bipolar level.

Some other facts have to be pointed out. They are concerned with the way the neurones work. First, three of them, namely photoreceptor, horizontal and bipolar cells, respond to light by means of hyperpolarization. These neurones do not produce action potentials. The second group, amacrine and ganglion cells, show a large variety of responses. They are action potentials in every one of the cases as well as depolarizing. Different types are reported in the literature[14-15]. The amacrine cells show transient depolarizing responses, including what are apparently all-or-nothing action potentials, at the onset or cessation of light. Ganglion cells could be divided into three types according to their response to illumination. 'On' units respond to the onset of illumination, 'off' units respond to the cessation of illumination, and 'on-off' units respond to both onset and cessation. Another classification is made on the basis of the action potentials produced in response to stimuli. Most cells produce 'transient' responses, with just a few action potentials immediately after a change in illumination. They are called $\alpha$ cells. On the contrary, $\beta$ cells give sustained responses to light.

Several retina models appear in the literature following these lines[13-15]. The studied configuration in this paper appears in Fig. 4 and it was partially reported by us[5–8]. Just two photoreceptors have been taken. This configuration is similar the one proposed by Dowling[15] to summarise the activity of the various retinal cells. As it can be seen, the receptor on the left is illuminated with a brief flash of light imposed on a dim background that illuminates both receptors, R1 and R2. A large response is observed in the stimulated receptor whereas the adjacent receptor that is not illuminated (right receptor) shows only a small

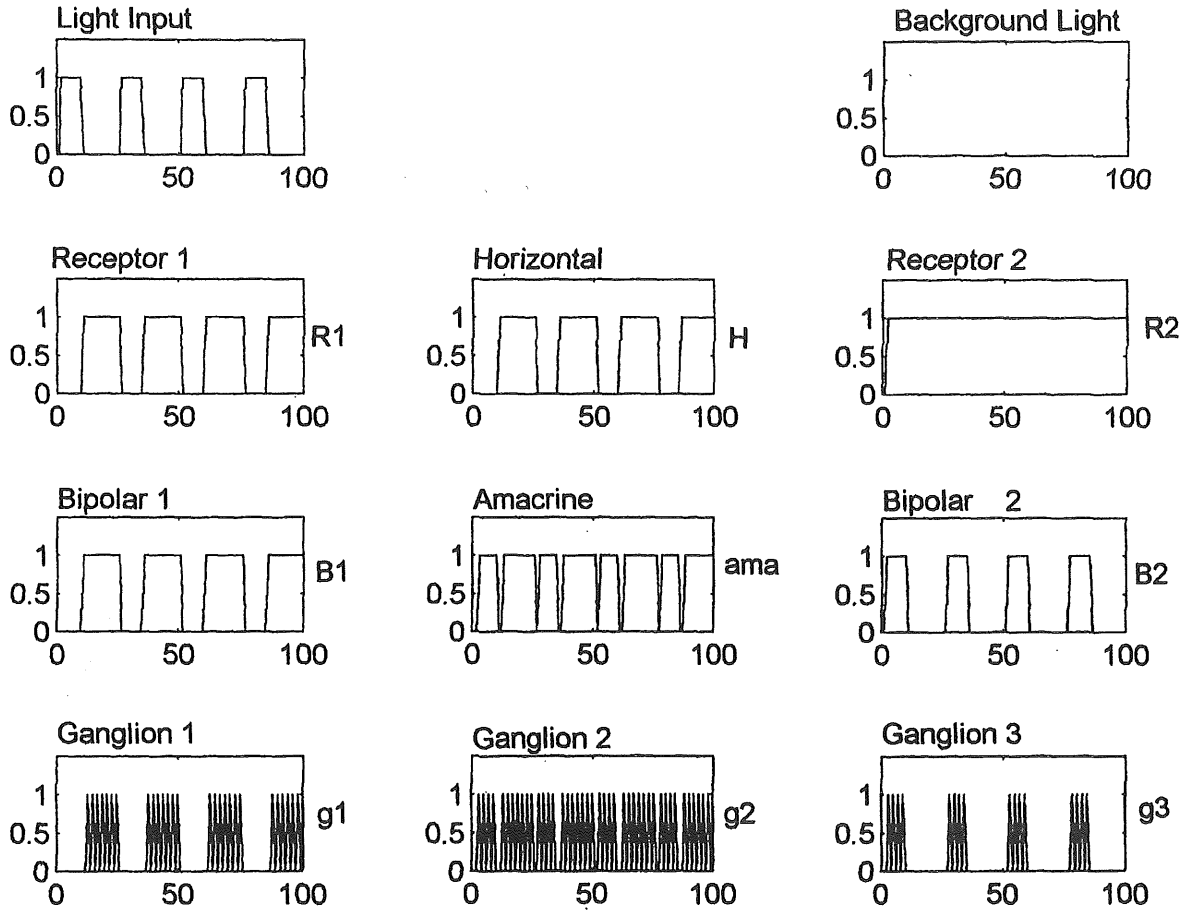


**Figure 6.-** Output signals from the ganglion cells at the retina adopted model and signals in the other different previous cells (photoreceptor, vertical, horizontal and amacrine cells).

response that probably reflects mainly the electrical coupling between the photoreceptor cells. Bipolar and horizontal cells are both activated by the receptors. The scheme of Fig. 4 shows that bipolar cell B1 is polarised strongly in a graded and sustained fashion by direct contacts with receptor R1. Moreover, this bipolar cell potential is antagonised by horizontal - bipolar cell B2 interaction. Bipolar cell B2 responds to indirect (surround) illuminations by depolarising. As it can be seen, the switch from hyperpolarizing to depolarising potentials along the surround illumination pathway occurs at the horizontal - bipolar junction.

Amacrine cell, A, responds to light mainly with transient depolarizing potentials at the onset and cessation of spot illumination. The responses of the two basic types of ganglion cells found in the vertebrate retinas appear to be closely related to the responses of the input neurones to the ganglion cells. The G1 ganglion cell has a receptive field organisation very similar to that of bipolar cells. Central illumination hyperpolarises both the bipolar and ganglion cells, B1 and G1, in a sustained fashion, and surround illumination depolarises the bipolar B2 and ganglion G2 cells in a sustained fashion. This type of ganglion cells appears to receive most of its synaptic input directly from the bipolar cell terminals through excitatory synapses. The ganglion cells illustrated in Fig. 1 are off-centre cells but there are some other types present in the vertebrate retinas. Ganglion cell G2 responds transiently to retinal illumination, much as the transient amacrine cells do. This type of response is the one adopted in our model.

Although this model is a very simple one, it is very useful to implement most of the functions performed at the mammalian retina. More complicated models can be obtained directly from this one.

The above indicated model has been computer by simulated by the scheme shown in Fig. 5. Results appear at Fig. 6.

Several possibilities appear from this structures. Fig. 6 shows just a part of them. This configuration, as it can be seen, has as its outputs three different types of signals. At ganglion 1 output is a train of pulses during the time there is no

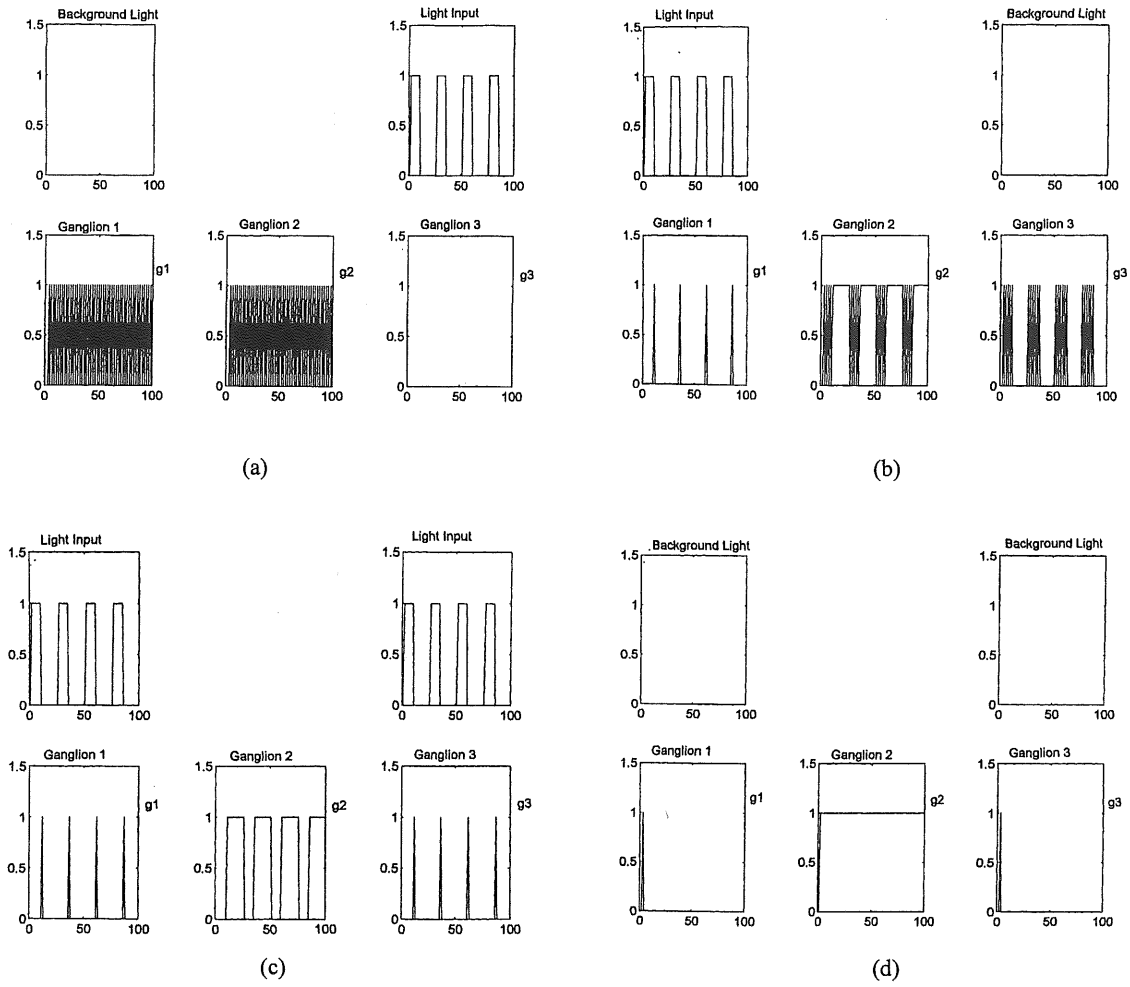


**Figure 7.-** Outputs from the ganglion cells corresponding to the situations indicated at the text.

light impinging onto the photoreceptor. Ganglion 2 gives a continuous train of pulses except at the moment when there is a change from light to darkness and viceversa. Finally, output of ganglion 3 is a train of pulses during the time interval there is light going into the receptor. If light changes its position form receptor on the left to receptor on the right, outputs are very different. They are shown in Fig. 7.a. Ganglion cell corresponding to the channel with light has no output signal. On the contrary, other two ganglion cells offer a continuos train of pulses.

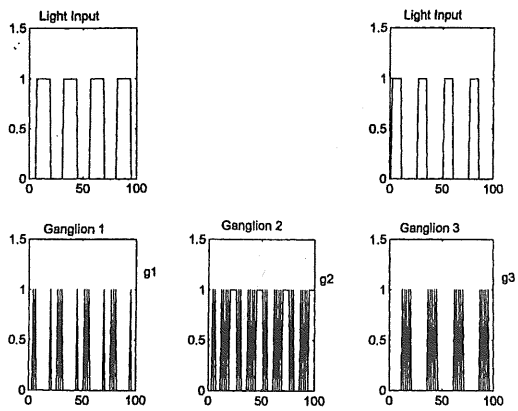


**Figure 8.-** Outputs corresponding to different time inputs at the receptors.

A first conclusion from the above results is that this configuration is able to give, as well as an information about the time duration of the input light, from where it comes to the receptors. Hence this configuration is an asymmetrical configuration.

If some of the internal connections to the scheme shown in Fig. 4 are changes, this structure may be converted to another one with a symmetrical behaviour. Results are shown in Fig. 7 (b)-(c)-(d). Figs 7 (b) corresponds to a similar situation as the previously studied. This result is the same one without regarding where is the light. Figs. 7 (c) – (d) offer the result when there is light impinging on both

receptors and when there is no light onto them.

A last result is shown in Fig. 8. It corresponds to the case when there is a periodic lighting to both receptors, but the signals have some differences with respect to the arriving time. The three analyzed ganglion cells give a similar train of pulses. But they offer some differences corresponding to the points where they have the beginning and the end. From the obtained information is possible to extract almost any information corresponding to the arriving light.

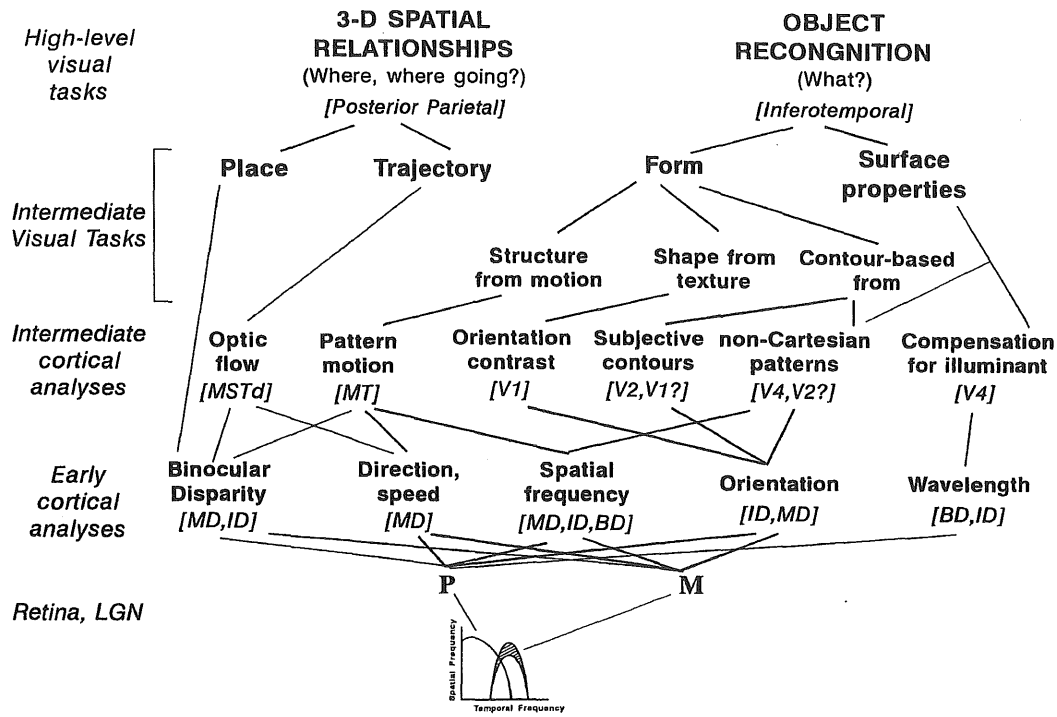


**Figure 9.-** Convergence and divergence of information at different stages of the visual processing. MD: magno-dominated. BD: blob-dominated. ID: interblob-dominated. P: Parvocellular streams. M: Magnocellular. streams

## 1. EXTENSION OF THE MODEL TO THE PRIMARY VISUAL CORTEX

As it has been pointed out at the beginning of this paper, any information captured at the retina goes to higher levels of the visual cortex. A very complex process occurs at each one of the successive layers. A summary of the present day knowledge of these processes is summarised at Fig. 9. It is a well known scheme presented by several authors in several places (see, for example, [16]).

Our present objective is to emulate a part of this behaviour, more in those aspects related with subjective or qualitative properties than with objective or quantitative. We think that these aspects need a more careful attention than the last ones because they have been the object of much less attention. In order to initiate our emulation we have started from a model as the one represented in Fig. 10. It is a very simplified model of the existing structure in the vertebrate visual system, going from the retina to the lower part of the visual cortex, but it may help us for understanding some possible mechanisms in capturing image information.

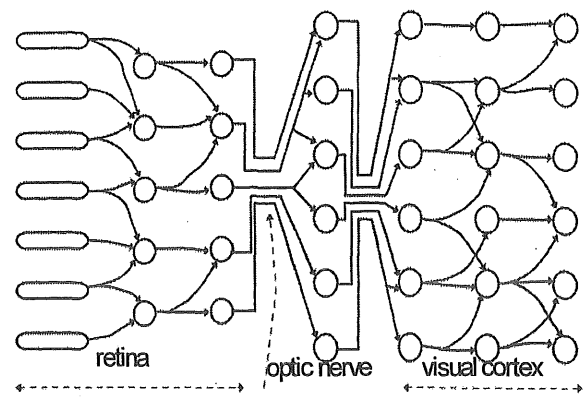


**Figure 10.-** Initial model of the visual system.

Our main task will be to construct a model as the above indicated one with main units the previously employed optical programmable logic cell. Hence, each one of the indicated block in Fig. 10 will be structures similar to the one shown in Fig. 3. An even more simplified model is the shown in Fig. 10. It is the basis for constructing the primary visual cortex. It is composed by six layers of cells interconnected in the way shown. Each one has two inputs, corresponding to the previous layer, and one output going to the following layer. The blocks are again of the same type, OPLCs, than before. The logic functions to be

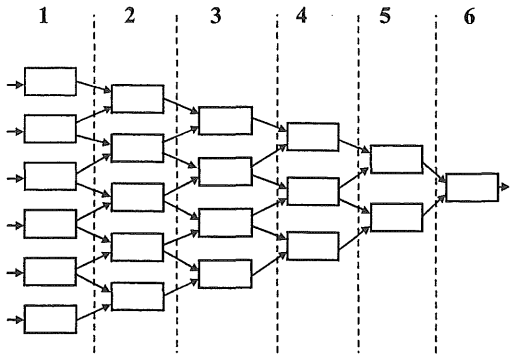


**Figure 11.-** Simplified model of the primary visual cortex based on the diagram of Fig. 9.

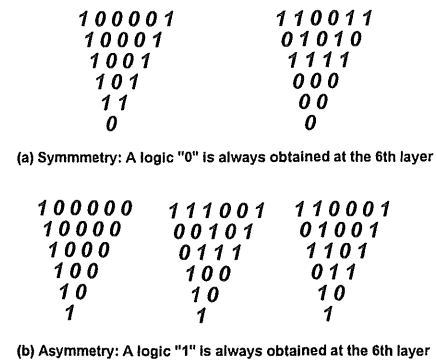


**Fig. 12.** Results obtained from Fig. 10 for different cases of the incident light symmetry.

performed by them depend on the type of interpretation it is wanted.

As a first example, if the property is desired to know is the symmetry of the light impinging onto the cells, the function to be performed by the OPLCs are simply XOR functions. Some examples are given in Fig 12. Light on a receptor gives a logic "1" and no-light gives a "0". In Fig. 12.a, a symmetric light acts on the first row of cells. In this case, the

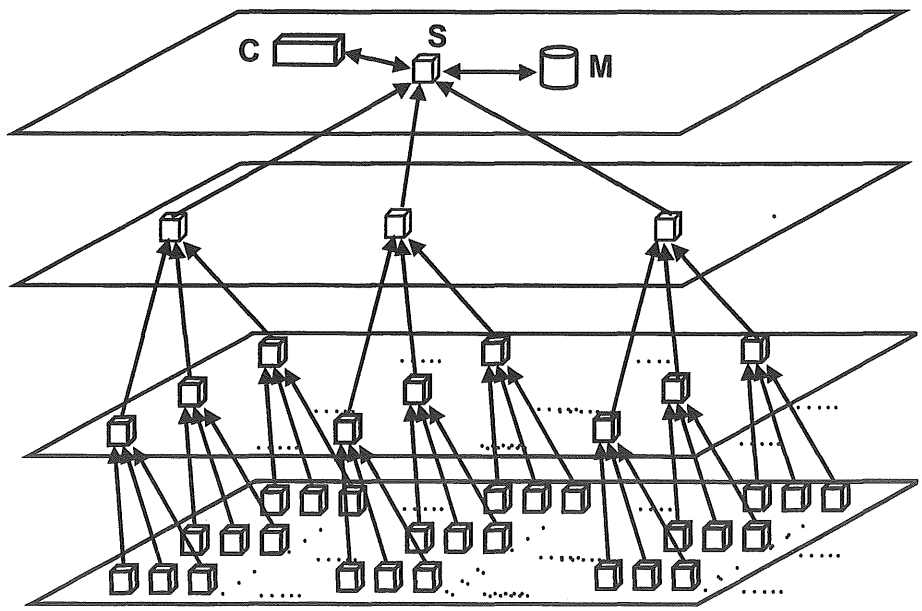


**Figure 13.-** Proposed 3D-structure designed to analyze higher order tasks in the visual processing.

obtained logic digit gives the results in higher levels of the system. As it can be seen, depending on the order of the symmetry, just zeros are obtained from a certain level on, the fifth row in the first case and the third row in the second one. On the contrary, when the light signal is asymmetric, as in Fig. 12.b, a logic "1" is always obtained at the fifth level of the processing layers. This study can be extended to obtain some other properties of the incident light. Dimension of the object and number of borders can be obtained in the same way.

From this configuration is easy to go to a higher order structure. The studied architecture we have analyzed is the one shown in Fig. 13. It is composed by four planes of cells arranged in the indicated form. This scheme allows to extend previous concepts to a bidimensional image. In this case the employed architecture is a 3D one. It is obvious that an electronic or optical implementation requires some more considerations than just the simple ones presented here. But the same concepts are easy to apply. S corresponds with the sensor element, C is the control system located there in order to recognise the type of information arriving to S and M is some possible memory.

## 5. CONCLUSIONS

The above reported model is able to process an special type of qualitative information better than a quantitative. one. The obtained result gives, without any kind of doubt, a too much simplified information. It is just binaries "ones" and "zeros", depending on some characteristics of the object. But this type of signal may be able to trigger some type of system connected with the presently reported architecture . For example, as we have shown[16], under certain circumstances, a set of new frequencies, no present previously at a string of neurons, may appear. These frequencies could be similar to the obtained at certain parts of the brain when a new sensation is perceived by a living body. The results reported here should be put together with the conclusions indicated there. The possibility to extend this model to higher levels of complexity could be done without no too much difficulty.

## ACKNOWLEDGEMENTS

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